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(54) PROCESS FOR MANUFACTURING HIGH-TENSILE HOT-ROLLED STEEL STRIP HAVING A LOW YIELD RATIO DUE TO ITS MIXED STRUCTURE.

(57) A process for obtaining C-Si-Mn-Cr hot-rolled steel strip having a mixed structure, a yield ratio (YR) as low as 65% or less, an excellent strength-elongation balance M, an excellent cold workability with less change in material quality, by the controlled stepwise cooling procedure between finish-rolling step and winding-up step. The process comprises adjusting the final temperature of finish-rolling hot-rolled steel strip containing 0.02% to 0.2% C, 0.05 to 2.0% Si, 0.5 to 2.0% Mn, and 0.3 to 1.5% Cr as necessary ingredients to 780°C, quenching it at a rate of 40°C s or faster depending upon the ingredients in the steel and hot-rolling history down to the temperature range where $\gamma - \alpha$ transformation efficiently takes place, maintaining the strip for 5 seconds or longer in this temperature range, then quenching at a rate of 50°C/s or faster between the maintaining temperature and a temperature range of 550 to 220°C.

EP 0 072 867 A1

A method for producing hot-rolled steel
sheets having a low yield ratio and a high
tensile strength due to dual phase structure

Technical Field

The present invention relates to a method for
producing hot-rolled steel sheets having a low yield ratio
and a high tensile strength due to dual phase structure and
intends to clarify the range of cooling regulating conditions
for producing a hot-rolled steel sheet having a low yield
ratio and a high tensile strength, and provided with the
properties same as or higher than those accomplished only
by a prior reheating method explained hereinafter through
a continuous annealing line without causing disadvantage
and inconvenience resulting from the reheating method by
firstly quenching at a specific cooling rate a steel sheet
having a specific component composition, which has been
subjected to a final rolling in hot rolling, maintaining
the quenched steel sheet at a specifically defined temper-
ature range and then subjecting the thus treated steel
sheet to second quenching at a specific cooling rate,
whereby the hot-rolled steel sheet having the above
described properties can be advantageously produced.

Recently, the demand of high tensile strength -
thin steel sheets has been rapidly increased mainly in
automotive field and this aims to ensure the safety of
drivers, reduce the car weight and improve the fuel cost

and this demand is required in the application other than automobiles for intending the increase of the toughness of the structure and the decrease of the weight of the structure.

In these applications, the thin steel sheets of a base material is usually subjected to a cold molding step, such as press forming and therefore such a sheet is required to have excellent cold formability.

As one means for satisfying the cold formability which is inconsistent with respect to high tensile strength steel sheets, it has been known that a metal structure is composed of a mixed structure (referred to as dual phase structure" hereinafter) wherein ferrite phase and martensite phase are dispersed and steels having such a dual phase structure show unique mechanical properties, that is low yield point, high tensile strength, and further very excellent strength-elongation balance and therefore these steel sheets are excellent in the cold formability.

The excellent cold formability of the dual phase structured high tensile strength thin steel sheets is due to the low yield ratio and the high ductility because the strength at a low strain zone is determined by a soft ferrite phase and the strength at a high strain zone is determined by a hard martensite phase (referred to as "the hard second phase" hereinafter). Furthermore, in these steel sheets, the work hardening is very high upon working

and the yield strength is increased. owing to the age hardening after the molding, so that the strength in the final product is not inferior to that of the general high tensile strength steels and these steel sheets have very practically useful properties.

The present invention can advantageously provide high tensile strength steel sheets having excellent properties due to the dual phase structure and occupies the technical field concerning the production.

Background Art

The most general method for producing the above described dual phase structured steel sheets comprises reheating a thin steel sheet up to γ+α zone by using a heat-treating apparatus of a prior continuous annealing line and then rapidly quenching the reheated steel sheet in the subsequent cooling step to transform γ portion formed in the heating step into martensite (referred to as "reheating method" hereinafter). But it is essential for the reheating method to add one step for the heat treatment and is not advantageous in view of economy and productivity.

On the other hand, it has been known to directly obtain the dual phase structure in a hot-rolling step without effecting the separate heat treating step (referred to as "hot-rolling method" hereinafter) but the cold formability of the dual phase structured steel sheets produced in the prior hot-rolling method is far inferior

to that of the steel sheets produced in the above described reheating method.

In order to improve the cold formability of the steel sheets having a high tensile strength of more than 50 kg/mm², which are mainly used in automotive field hereafter, it is necessary that the yield ratio YR is less than 70%, preferably less than 65% and the following value M of the strength-elongation balance parameter which is clarified and proposed by the inventors as an indication of the cold formability

$$M = 0.45TS + E\ell$$

wherein TS is tensile strength (kg/mm²) and Eℓ is total elongation (%), is 60 or more, but the dual phase structured steel sheets produced in the prior hot-rolling method can not reach the level satisfying this value and these require-ments are satisfied only by the above described reheating method.

In general, the yield ratio and the strength-elongation balance of the dual phase structured high tensile strength steel sheets vary depending upon the mixing ratio of ferrite phase to the hard second phase, the state of the hard second phase dispersed and ferrite grain size and the like and in order to obtain the above described yield ratio and parameter value M of strength-elongation balance, it is necessary that the ferrite fraction is more than 75%, the hard second phase is finely

and uniformly dispersed and ferrite grain size is satis-factorily large.

When pearlite and bainite are mixed in the structure, the mechanical properties are considerably deteriorated.

In the practical hot-rolling operation, the actual necessary time from a final finishing roller to a coiler is about 10-40 seconds and the cooling means in a run-out table is limited to either of a laminate flow, water cooling through jet or air cooling, so that the hot-rolling process is less in the freedom for controlling the cooling condition than the reheating method and the hot-rolling method has a further problem in this point.

Therefore, in the case of the hot-rolling method, it is necessary to take into careful consideration so that the dual phase structure defined as described above can be obtained under the severely limited condition range.

Even though the actual transforming phenomenon caused in the hot-rolling step should be fully clarified and checked in order to overcome such a difficulty, it has never been attempted to fully check the three optimum conditions of the chemical components, rolling condition and cooling condition which are factors influencing upon . the transforming behavior and further although these influencing factors have the mutual correlation, this point has never been taken into consideration.

Thus, when the prior hot-rolling method is checked in view of these points, said method has not been satisfied.

Discussion will be made hereinafter with respect to the problems of the already proposed main methods for producing the dual phase structured high tensile strength steel sheets through hot-rolling method and to the difference of said methods from the method of the present invention.

A first prior method, for example, Japanese Patent Laid Open Specification No. 34,659/80 or No. 62,121/80, comprises that a part of the final rolling is carried out in a temperature range of two phases of $\gamma + \alpha$ to effect a means for promoting the transformation of γ into α owing to the strain induction and then a cooling condition in which stay time at a temperature range at which γ is easily transformed into α is prolonged as far as possible, is adopted. However, in these methods, the drawback owing to the rolling in the two phase zone can not be avoided, so that when the rolling in the two phase zone is effected, ferrite phase and martensite phase in the final structure show the fiber-like dispersed state and anisotropy of mechanical properties due to this state is caused and the rolling strain remains in ferrite grains, so that the elongation property is deteriorated and the increase of the ferrite fraction mainly relies upon the increase of number of ferrite grains, so that the ferrite grains

becomes fine and therefore the yield ratio becomes relatively higher.

In these methods, it has been difficult as mentioned hereinafter to obtain the steel sheets of a yield ratio $YR \leqq 65\%$ and a parameter M of strength-elongation balance = $[0.45TS + E\ell] \geqq 60$. A prior second method, as shown in, for example Japanese Patent Laid Open Specification No. 65,118/79 comprises that after completing the final rolling at a temperature of higher than Ar_3 point, cooling is discontinued when the temperature of a steel sheet becomes within a range of Ar_3-Ar_1 in the course of rapid quenching of the steel sheet which has finished the final rolling at a temperature of higher than Ar_3 point, on the run-out table, and said temperature is held for a given time and then the rapid quenching is again effected. This method intends to effectively progress the transformation of γ into α during the intermediate holding time but does not cause the quality drawbacks as in the case of the above described rolling in the two phase zone and is an excellent idea in view of effective use of the limited time but even though the optimum cooling condition strongly relies upon the chemical components of the base material and the rolling hysteresis at the upper stream steps, these points are neglected and a mere two stage of cooling or a broad holding temperature range of Ar_3-A_1 is only set, so that a high improvement of quality can not be

attained. That is, the problem of the method of this prior art consists in that the countermeasurement regarding the above described points has not been yet clarified. When a trial calculation is made with respect to the examples in this publication, the quality level does not satisfy the yield ratio YR$\leq$60% and the parameter M of strength-elongation balance = [0.45TS + Eℓ] $\geq$ 60 and is substantially equal to that of the prior hot-rolling method.

In this prior publication, a simple C-Si-Mn system is only selected and it has never been noticed to use more advantageous C-Si-Mn-Cr system for forming the dual phase structure in view of the transforming property.

Disclosure of Invention

The present invention has clarified the strict cooling conditions following to the hot final rolling for obtaining the best quality, whereby the condition range can be always easily defined even when the chemical components and the rolling condition are varied.

The present invention has been made in order to advantageously improve the above described all problems of the prior methods and is constructed with the essential matters which define three optimum requirements of the chemical components of the base material, the temperature when the final rolling is finished and the cooling condition on the run-out table. The present invention provides

a method for producing dual phase structured steel sheets having a low yield ratio, a high tensile strength, an excellent shape stability in formed articles and a low variation in coil, which have more excellent cold formability than the reheating method, that is a yield ratio YR≦65% and a parameter M of strength-elongation balance ≧ 60.

The present invention lies in a method for producing hot-rolled steel sheets having a low yield ratio and a high tensile strength due to dual phase structure, characterized in that when a hot-rolled steel sheet containing 0.02-0.2% by weight of C, 0.05-2.0% by weight of Si, 0.5-2.0% by weight of Mn and 0.3-1.5% by weight of Cr as the essential components, and if necessary at least one element selected from each group of the first group components consisting of not greater than 1% by weight of Cu, Ni and Mo and not greater than 0.02% by weight of B, the second group components consisting of not greater than 0.2% by weight of Nb, V and Ti and the third group components consisting of not greater than 0.05% by weight of REM and Ca, and not greater than 0.1% by weight of Al and not greater than 0.15% by weight of P as a preferable component, is cooled on a run-out table after final rolling and then coiled, a temperature FT when the final rolling is finished, is higher than 780°C, the final rolled steel sheet is rapidly quenched at a cooling rate of more than 40°C/S from the completion of the final rolling to a temperature

range from a temperature T_N, shown by the following
formula (1), +40°C to the temperature T_N-40°C, is held at
said temperature range for more than 5 seconds and then
again rapidly quenched at a cooling rate of more than
50°C/S from the held temperature to a temperature range of
550-200°C, whereby a hot-rolled steel sheet having the
yield ratio≦65% and the parameter M of strength-elongation
balance shown in the following formula (2) ≧ 60 and low
variation of steel qualities and excellent cold formability
is obtained.

$$T_N = 582 + 44Si\% - 33Mn\% + 25Cr\% - 3Cu\% - 9Ni\% + 5Mo\%$$
$$+ (0.8 - C\%) (48 - 25Si\% + 57Mn\% - 15Cr\% + 10Cu\%$$
$$- 15Ni\% - 28 Mo\%) + 70\exp\{-(\frac{FT(°C)-780}{100})^4\} \quad ... (1)$$

$$M = 0.45TS + E\ell \qquad\qquad\qquad ...... (2)$$

wherein TS is tensile strength (kg/mm²) and Eℓ is total
elongation (%). The reason why C-Si-Mn-Cr system chemical
components are particularly defined as a base material of
hot-rolling steel sheet in the present invention is as
follows.

C :

      C is an element important for improving the
hardenability and the strength of martensite by being
diffused and transferred into γ phase in the transformation

of γ into α in the course of cooling, but when the amount is excessive, the fraction of the second phase becomes excess and the formability is deteriorated and the weldability is adversely affected, so that the moderate range is 0.02-0.20%.

Si :

This element is high in the solid solution hardening and can increase the strength without deteriorating the yield ratio and the strength-elongation balance and activates the transformation of γ into α and promotes the enrichment of C into γ phase. Thus, this element has useful properties for forming the dual phase structure and further improves the refining ability of steel as a de-oxidizing element and the content of 0.5% or more is very effective but when the content exceeds 2.0%, the effect is saturated and the economical disadvantage is brought about, so that the content is 0.05-2.0%.

Mn :

This element is a relatively inexpensive alloying element for improving the hardenability of steels and is a main element of additive alloying components and needs at least 0.5% in order to ensure the hardenability of steels but when the amount exceeds 2.0%, the weldability is adversely affected and the rate of transforming γ into α is decreased and the tendency of increasing the fraction of the second phase is shown, so that the content is defined to be 0.5-2.0%.

Cr :

This element is an element for improving the hardenability as well known and is a particularly important element in the present invention. That is, other elements for improving the hardenability have generally a function for retarding the transformation of Ar_3 and therefore have an adverse influence upon the increase of the fraction of ferrite but Cr does not give a great influence upon the transformation of Ar_3 and serves to improve the stability of the remaining γ phase and makes the formation of the dual phase structure easy. In order to develop this effect, a content of at least 0.3% is necessary and the upper limit is defined to be 2% in view of the economy. When it is intended to reduce variation of the quality in the coil, it is preferable to contain at least 0.5%.

Other than the above described essential components, the selective components as described hereinafter may be contained in the present invention, whereby the desired effects can be further improved.

Cu, Ni, Mo :

Cu has effect of solid solution hardening, Ni has effect for improving solid solution hardening and hardenability and Mo has effect for improving hardenability and these elements are the equivalent elements in view of the contribution to increase of strength in an amount of not greater than 1%. But any of these elements are expensive

and when the total amount exceeds 1%, such an amount is
not economic, so that the upper limit is defined to be 1%.
B :

B is a useful element for increasing the stability
of the quality, because this element has the same effect
as the above described components in a samll amount of not
greater than 0.02% regarding the function of increasing
the strength owing to improvement of hardenability and
further makes the formation of the dual phase structure
easy. But this effect is saturated in an amount of exceeding
0.02%, so that the upper limit is defined to be 0.02%.
Nb, Ti, V :

These elements have very high effect for restrain-
ing formation of fine grains and recrystallization of
γ grains, so that when a moderate amount of not greater
than 0.2% is contained, the rate of transforming γ into α
after the final rolling can be increased by means of these
elements, so that these elements are useful. However,
when said amount exceeds 0.2%, the precipitation hardening
becomes high and the yield ratio is increased, so that
such an amount is not desirable and the upper limit of any
elements is defined to be 0.2%. Ca and REM (Ce + La) bond
to S in steels which gives adverse influence upon the
mechanical properties, to restrain the harm of S, so that
the use of these elements is very effective but when the
amount exceeds 0.05%, the refining degree is reversely

degraded and the mechanical properties are deteriorated,
so that the upper limit is defined to be 0.05%.

Al :

If this element is used as a deoxidizing element,
the refining ability of steels is improved and the
formability is improved but the effect is saturated at
0.10%, so that the upper limit is 0.10%.

P :

This element has the similar property to Si in
view of the solid solution hardening and the activation of
transformation of γ into α and if the amount is not greater
than 0.15%, even when this element is positively added to
an amount which exceeds the amount as an incidental impurity,
there is no problem but when the amount exceeds 0.15%, the
segregation is caused in the steels whereby the mechanical
properties are deteriorated and the weldability or the
fatigue property is adversely affected, so that the amount
is limited to 0.1%.

The most important point in the course of formation
of the dual phase structure in the hot-rolling method is
the step where polygonal ferrite is precipitated from
γ phase at the point where the final rolling is completed,
because the delay of this precipitation has direct relation
to reduction of the fraction of ferrite in the final
structure and indirect relation to deficiency of enrichment
of C into the remaining γ phase due to the precipitation

of ferrite, and the hardenability is lowered and the fear
of mixture of pearlite and bainite into the hard second
phase is increased.

The cooling conditions of the present invention
are based on the above described viewpoints and the principal
object lies in that the transformation of γ into α is
progressed to the maximum limit within the limited cooling
time on the run-out table and the content consists of three
stages of cooling step as shown in Fig. 1. Explanation
will be made hereinafter with respect to the function and
the reason of defining the condition in each stage with
reference to Fig. 1.

The transformation property after the hot-rolling
is varied by the rolling hysteresis other than the chemical
components of the base material and particularly the
latter influence upon the transforming behavior of γ into
α is high, and as the size of γ grains when completing the
hot-rolling is finer and the working strain amount in
γ grains is larger, the transformation of γ into α is
promoted. However, when a usual steel finishes rolling at
a temperature of higher than Ar_3 point, the worked γ grains
are rapidly recovered and cause the recrystallization
immediately after completion of rolling and the above .
described phenomenon is relaxed. Accordingly, the cooling
in the first stage in Fig. 1 mainly aims at to satisfactorily
restrain this recovery and recrystallization and to maintain

the cooling to the temperature range where the transformation
of γ into α is efficiently caused and in order to obtain
this effect, the cooling rate α_1 from the temperature when
the final rolling is finished to the transforming temperature
range must be a rapid quenching of a cooling rate of more
than 40°C/S. When α_1 is slower than this rate, the above
described effect disappears and therefore the low yield ratio
and the strength-elongation balance aimed in the present
invention can not be obtained and the loss of the necessary
time occurs. The reason why the temperature range when the
first stage of rapid quenching is finished, is defined, is
determined by the object of the second stage mentioned
hereinafter. The rate of transforming γ into α depends
upon the nucleus forming rate and the nucleus growing rate
and the temperature range at which these rates becomes
maximum, is present. Therefore, in order to efficiently
progress the transformation of γ into α, it is desirable
that the stay time within this temperature range is made
longer as far as possible and the holding at the second
stage in this invention is effected for this purpose and for
the purpose, the holding at the temperature range of from
T_N + 40°C to T_N - 40°C for more than 5 seconds is necessary.

T_N as seen from the above described formula (1), ·
depends upon the components in the steel and the température
FT when the final rolling is finished, among the hot-rolling
hysteresis, but fairly greatly varies depending upon the

components and the inventors have made experiments in a broad range and found the relation of the above described formula (1) which fits advantageously to the object of the present invention. When T_N is not covered by the above described range, the following objects of the present invention can not be attained (see Examples).

$$YR \leqq 65\%$$
$$[0.45TS + E\ell] \geqq 60$$

The upper limit of the holding time is not determined by the mechanical properties but the time is limited to 30 seconds in view of the time limit of the processing step but if the problems of the productivity and installation are neglected, it is permissible to exceed the defined range and, for example when a heat insulating means or a heating means for this purpose is provided on the run-out table, the better results can be expected. The third range of cooling is effected for transforming the untransformed γ phase into martensite and the essential matter consists in to prevent the transformation into pearlite and bainite and it is not always necessary to cause the transformation into martensite in this cooling step. In the present invention, the cooling rate α_2 must be more than 50°C/S and the temperature when the cooling is finished must be lower than 550°C. The reason why the lower limit of the temperature when the cooling is finished is defined to be

200°C is as follows. When the rapid quenching is effected to a temperature of lower than 200°C, there is no chance that C present in solid solution in imbalance in ferrite phase is precipitated and the mechanical deterioration is brought about in the product, so that such a temperature is not preferable. When the temperature when the cooling is finished is lower than 400°C, the timing of transformation into martensite is not coincident in the transversal direction and the longitudinal direction of the steel sheet and an inferior form is caused, that is waveforms are formed at the transversal edge portions of the sheet. Therefore, in order to avoid this defect, it is preferable to select the temperature when the cooling is finished, within the temperature range of 400°C-550°C.

By satisfying the above described cooling conditions from the finishing of the hot-rolling to the coiling, the yield ratio YR value becomes 65% or less and the parameter M of the strength-elongation balance becomes 60 or more. In the above described Japanese Patent Laid Open Specification No. 65,118/79, it has been attempted that the parameter M of strength-elongation balance is estimated by the product of the tensile strength with the elongation as an indication of strength-elongation balance. The inventors have studied in detail this balance with respect to the relation of the formation of cracks or neckings caused upon molding of parts of structures subjected to various

high grade of complicated deformations, such as projecting
deformation, curving deformation, elongating frange deforma-
tion and the like as in the molding of wheel disc of
automotive parts to the tensile strength, TS, total elonga-
tion and El of the materials to be molded, and found that
the adoption of the value of 0.45TS + El as the parameter
satisfies the actual requirement as the indication of the
cold formability of the materials to be molded, which
shows the limit of forming cracks and neckings in the
above described molding.

Brief Description of the Drawings

Fig. 1 is a graph for illustrating the cooling
requirements of the present invention; and

Fig. 2 and Fig. 3 are graphs showing the relations
of YS to TS and El to TS with respect to the prior dual phase
structured steel sheets and examples of the present invention.

Best Mode of Carrying out the Invention

The tensile properties (JIS No. 5 tensile test
piece) of hot-rolled steel strips (2.8 mmt) produced by
hot-rolling steels having chemical composition shown in
Table 1 under the conditions shown in Table 2 are shown in
Table 2.

In Table 1, steel A is a comparative sample, .
steels B-E consist of the essential composition of C-Si-Mn-Cr
system and steels F-N are samples containing additionally
the selective components.

Table 1

(wt.%)

	C	Si	Mn	P	S	Al	Cr	Cu	Ni	Mo	B	Nb	V	Ti	REM	Ca
A	0.07	1.02	1.52	0.015	0.007	0.015	-	-	-	-	-	-	-	-	-	-
B	0.06	0.98	1.23	0.012	0.006	0.021	0.95	-	-	-	-	-	-	-	-	-
C	0.05	1.00	1.25	0.016	0.007	0.005	0.35	-	-	-	-	-	-	-	-	-
D	0.05	1.04	1.24	0.014	0.009	0.008	0.57	-	-	-	-	-	-	-	-	-
E	0.05	0.97	1.24	0.009	0.012	0.013	1.29	-	-	-	-	-	-	-	-	-
F	0.06	1.31	1.35	0.018	0.015	0.035	1.16	-	0.25	-	-	-	-	-	-	-
G	0.06	1.05	1.39	0.021	0.011	0.033	1.09	-	-	0.30	-	-	-	-	-	-
H	0.06	0.95	1.33	0.013	0.014	0.027	1.20	0.30	-	-	-	-	-	-	-	-
I	0.04	0.15	1.57	0.015	0.005	0.019	1.40	-	-	-	-	0.021	-	-	-	-
J	0.07	0.16	1.55	0.014	0.003	0.040	0.35	-	-	-	-	-	0.050	-	-	-
K	0.08	0.70	1.25	0.017	0.006	0.009	0.80	-	-	-	-	-	-	0.032	-	-
L	0.10	1.20	0.80	0.019	0.008	0.025	0.56	-	-	-	0.009	-	-	-	-	-
M	0.05	1.03	1.32	0.015	0.005	0.018	0.95	-	-	-	-	-	-	-	0.021	-
N	0.05	1.01	1.28	0.014	0.003	0.033	0.97	-	-	-	-	-	-	-	-	0.0008

Table 2(a)

Sample No.	Test steel	T_N (°C)	FT (°C)	α_1 (°C/S)	T_1 (°C)	Δt (sec)	T_2 (°C)	α_2 (°C/S)	T_3 (°C)	CT (°C)	YS(0.2) (kg/mm²)	TS (kg/mm²)	El (%)	YR=$\frac{YS_{0.2}}{TS}$×100 (%)	M=(0.45TS+El)	Remarks
1	A	718	840	75	730	5	710	125	460	460	43.5	57.2	30.9	76	56.6	Comparative method
2	"	"	"	"	750	12	700	"	"	"	43.6	55.9	33.8	78	58.9	"
3	"	"	"	"	"	"	"	"	350	350	43.6	62.3	29.9	70	57.9	"
4	B	735	820	-	820	8	770	"	470	470	50.5	72.1	23.9	70	56.3	"
5	"	"	"	75	800	9	750	"	460	460	46.4	69.3	25.6	67	56.8	"
6	"	"	"	"	790	10	740	"	465	465	42.7	67.8	27.1	63	57.6	"
7	"	"	"	"	780	11	730	"	470	470	39.1	65.2	29.3	60	58.6	"
8	"	"	"	"	770	12	720	"	465	465	36.1	63.3	34.1	57	62.6	Present invention
9	"	"	"	"	760	"	710	"	460	460	35.7	62.7	34.9	57	63.1	"
10	"	"	"	"	750	"	700	"	455	455	36.5	61.9	34.3	59	62.1	"
11	"	"	"	"	740	13	690	"	460	460	39.7	60.2	32.5	66	59.6	Comparative method
12	"	"	"	"	730	"	680	"	465	465	41.5	59.3	31.6	70	58.3	"

Table 2(b)

Sample Test No.	Test steel	T_N (°C)	FT (°C)	α_1 (°C/S)	T_1 (°C)	Δt (sec)	T_2 (°C)	α_2 (°C/S)	T_3 (°C)	CT (°C)	YS(0.2) (kg/mm²)	TS (kg/mm²)	El (%)	YR=$\frac{YS_{0.2}}{TS}$×100 (%)	M=(0.45TS+El)	Remarks
13	B	735	820	75	720	14	670	125	465	465	44.0	58.6	32.3	75	58.7	Comparative method
14	"	"	"	25	765	12	700	"	450	450	48.1	68.7	26.3	70	57.2	"
15	"	"	"	75	770	2	755	"	460	460	47.8	67.4	26.8	69	57.1	"
16	"	"	"	"	760	12	700	10	470	470	46.6	57.5	31.4	81	57.3	"
17	"	"	"	"	760	12	710	125	620	600	47.4	57.8	30.1	82	56.1	"
18	C	728	"	"	740	8	710	"	440	435	37.9	60.2	33.5	63	60.6	Present invention
19	D	732	"	"	750	"	715	"	410	400	38.2	62.6	33.0	61	61.2	"
20	E	741	"	"	755	"	725	"	440	440	36.6	66.5	32.9	55	62.8	"
21	F	744	800	75	765	14	725	125	510	500	43.8	69.5	30.2	63	61.5	"
22	G	723	850	"	770	"	710	"	490	490	41.7	70.7	29.9	59	61.7	"
23	H	742	780	"	765	"	720	"	375	370	40.9	67.1	31.2	61	61.4	"
24	I	683	880	"	695	8	670	"	455	455	35.6	56.5	36.9	63	62.3	"

Table 2(c)

Sample No.	Test steel	T_N (°C)	FT (°C)	α_1 (°C/S)	T_1 (°C)	Δt (sec)	T_2 (°C)	α_2 (°C/S)	T_3 (°C)	CT (°C)	YS(0.2) (kg/mm²)	TS (kg/mm²)	El (%)	$YR=\frac{YS_{0.2}}{TS}\times100$ (%)	$M=(0.45TS+El)$	Remarks
25	J	694	850	75	715	16	665	125	505	490	38.1	59.6	35.7	64	62.5	Present invention
26	K	718	840	"	755	20	680	"	490	480	41.2	64.3	33.7	64	62.6	"
27	L	731	790	"	760	28	695	"	425	425	40.2	64.8	32.1	62	61.3	"
28	M	740	800	"	750	12	710	"	410	410	33.7	60.1	36.6	56	63.6	"
29	N	731	840	"	735	"	700	"	420	420	34.7	60.8	36.0	57	63.4	"

Note : α_1 ... Primary cooling rate

α_2 ... Secondary cooling rate

T_1 ... Temperature when finishing the primary cooling.

T_2 ... Temperature when finishing the intermediate holding step.

T_3 ... Temperature when finishing the secondary cooling.

Δt ... Intermediate holding time

CT ... Coiling temperature.

YS ... Yield point (stress corresponding to 0.2% of permanent strain).

The results in Table 2 are arranged in the correlation of TS-YS and TS-Eℓ and the obtained results are shown in Fig. 2 and Fig. 3.

The following facts are found from Table 2, Fig. 2 and Fig. 3.

(1) In the steels of which the chemical components are not covered by the range of the present invention, even if the hot-rolling condition follows to the method of the present invention, the following requirements can not be attained.

$$YR \leqq 65\%, \qquad M \geqq 60,$$

(Sample Nos. 1, 2 and 3)

(2) If the chemical composition is within the range of the present invention, even if the selective components are used, the steel qualities aimed in the present invention can be obtained (Sample Nos. 18-29).

(3) When the cooling conditions are not covered by the range of the present invention, the aimed steel qualities can not be obtained. (Sample Nos. 4-7, 11-13 do not satisfy the requirement of temperature T_1 or T_2. Sample No. 15 does not satisfy the requirement of Δt. Sample Nos. 14 and 16 do not satisfy the requirement of α_1 or α_2. Sample No. 17 does not satisfy the requirement of T_3).

(4) The mechanical properties of the steel sheets produced following to the requirements of the present

invention are far more excellent than the dual phase structured steel sheets produced in the prior hot-rolling method and are substantially equal to the best properties in the prior reheating method.

As mentioned above, according to the present invention, the dual phase structure can be effectively controlled only by defining the composition of the hot-rolled steel sheets and the cooling condition after completing the final rolling to the coiling, and the properties of the steel sheets, which are much more excellent than those in the case of the prior hot rolling method and can be comparable to the best results in the reheating method, can be easily obtained without needing the reheating step or the similar procedure and the low yield ratio due to the above described dual phase structure can be realized without varying the quality and the cold formability of the high tensile strength hot rolled steel sheets can be greatly improved.

Claim

1.   Method for producing hot-rolled steel sheets
having a low yield ratio and a high tensile strength due
to dual phase structure, characterized in that when a
hot-rolled steel sheet containing 0.02-0.2% by weight
of C, 0.05-2.0% by weight of Si, 0.5-2.0% by weight of Mn
and 0.3-1.5% by weight of Cr as the essential components,
and if necessary at least one element selected from each
group of the first group components consisting of not
greater than 1% by weight of Cu, Ni and Mo and not greater
than 0.02% by weight of B, the second group components
consisting of 0.2% by weight of Nb, V and Ti and the third
group components consisting of not greater than 0.05% by
weight of REM and Ca, and not greater than 0.1% by weight
of Al and not greater than 0.15% by weight of P as a
preferable component, is cooled on a run-out table after
final rolling and then coiled, a temperature FT when the
final rolling is finished, is higher than 780°C, the final
rolled steel sheet is rapidly quenched at a cooling rate
of more than 40°C/S from the completion of the final
rolling to a temperature range from a temperature T_N, shown
by the following formula (1), +40°C to the temperature
T_N - 40°C, is held at said temperature range for more than
5 seconds and then again rapidly quenched at a cooling
rate of more than 50°C/S from the held temperature to

a temperature range of 550-200°C, whereby a hot-rolled steel sheet having the yield ratio ≦ 65% and the parameter M of strength-elongation balance shown in the following formula (2) ≧ 60 and low variation of steel qualities and excellent cold formability is obtained.
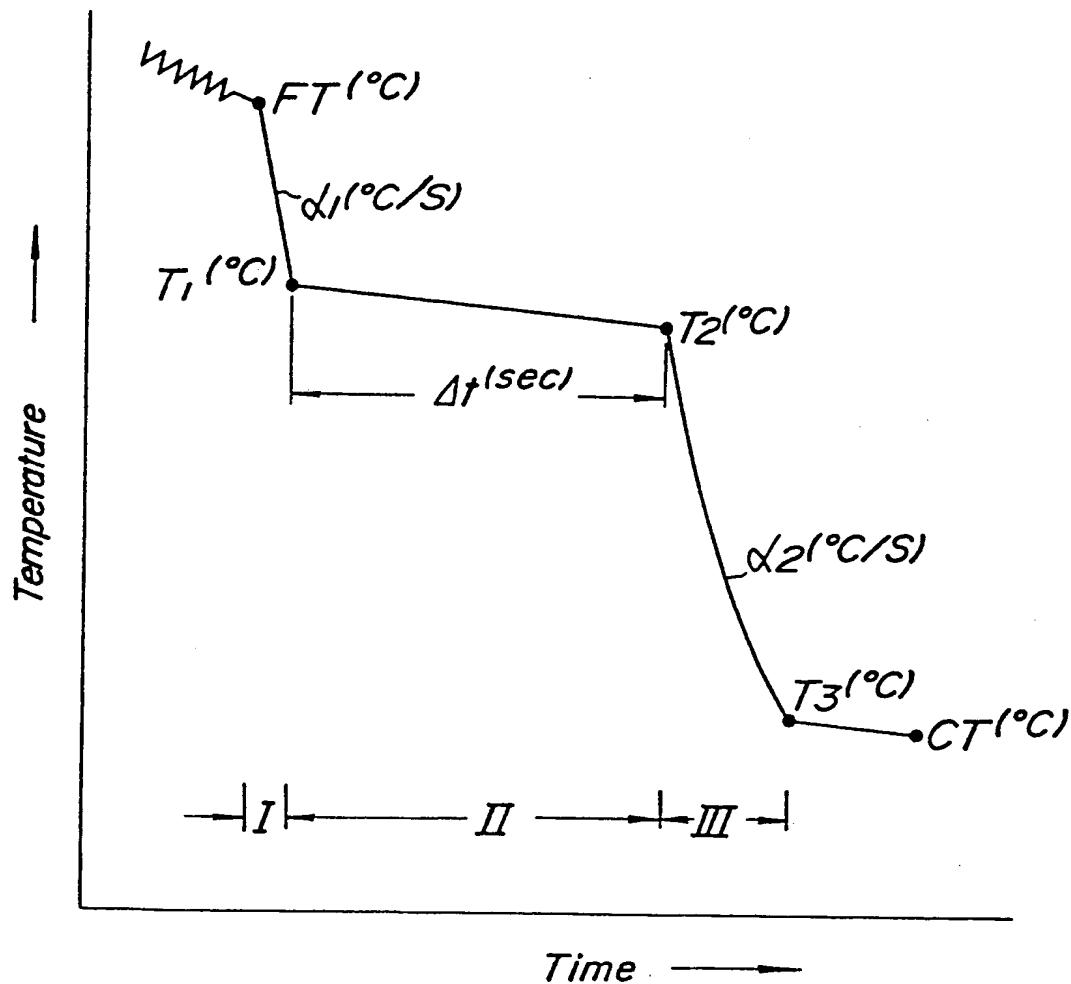
$$T_N = 582 + 44Si\% - 33Mn\% + 25Cr\% - 3Cu\% - 9Ni\% + 5Mo\%$$
$$+ (0.8 - C\%)(48 - 25Si\% + 57Mn\% - 15Cr\% + 10Cu\%$$
$$- 15Ni\% - 28 Mo\%) + 70exp\{-(\frac{FT(°C)-780}{100})^4\} \quad \dots (1)$$

$$M = 0.45TS + E\ell \qquad \dots\dots (2)$$

wherein TS is tensile strength (kg/mm²) and Eℓ is total elongation (%).

FIG. 1

Figure showing temperature versus time curve with labeled points: FT (°C), α_1 (°C/S), T_1 (°C), T_2 (°C), Δt (sec), α_2 (°C/S), T_3 (°C), CT (°C). Regions I, II, III marked along the time axis.
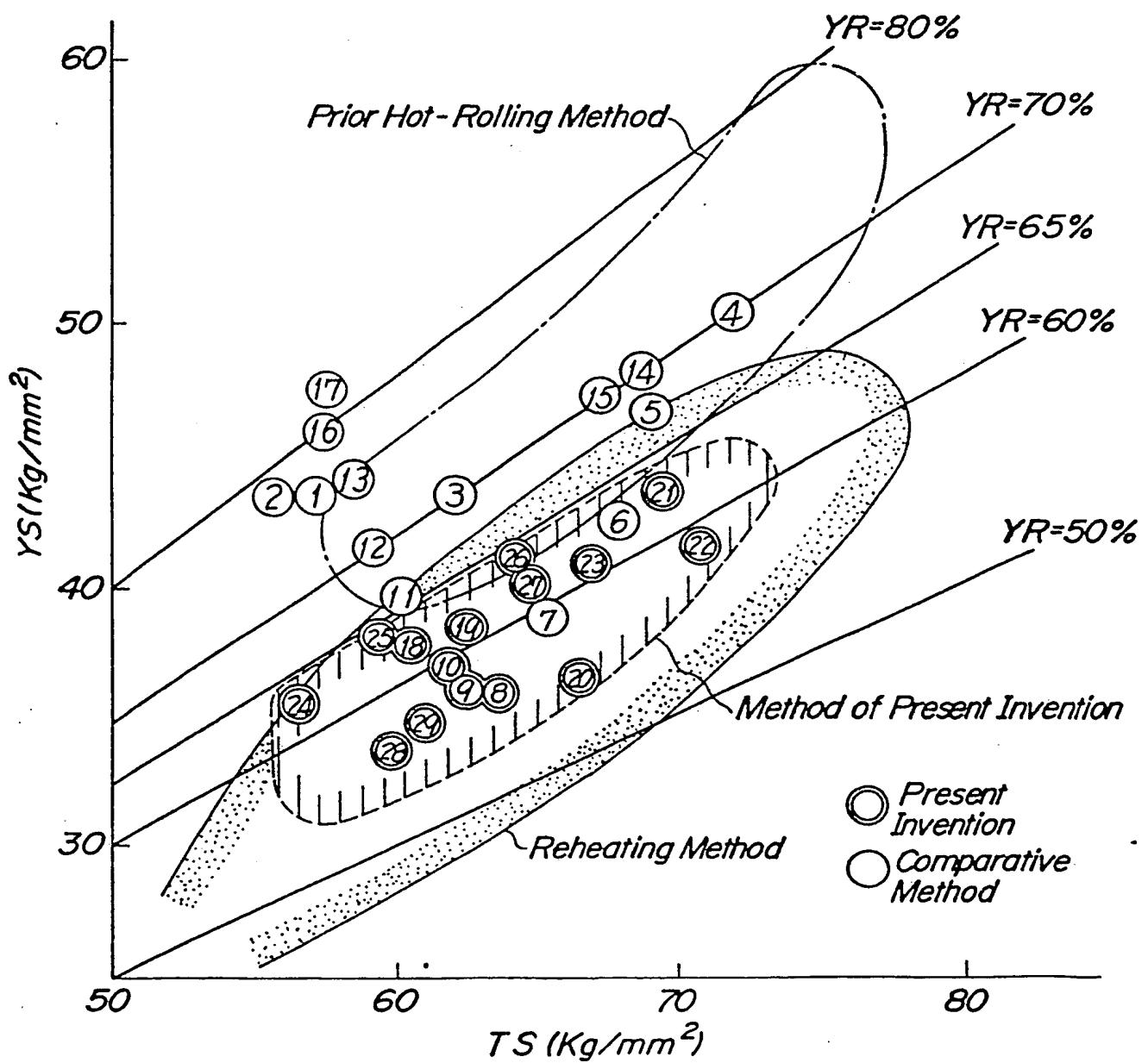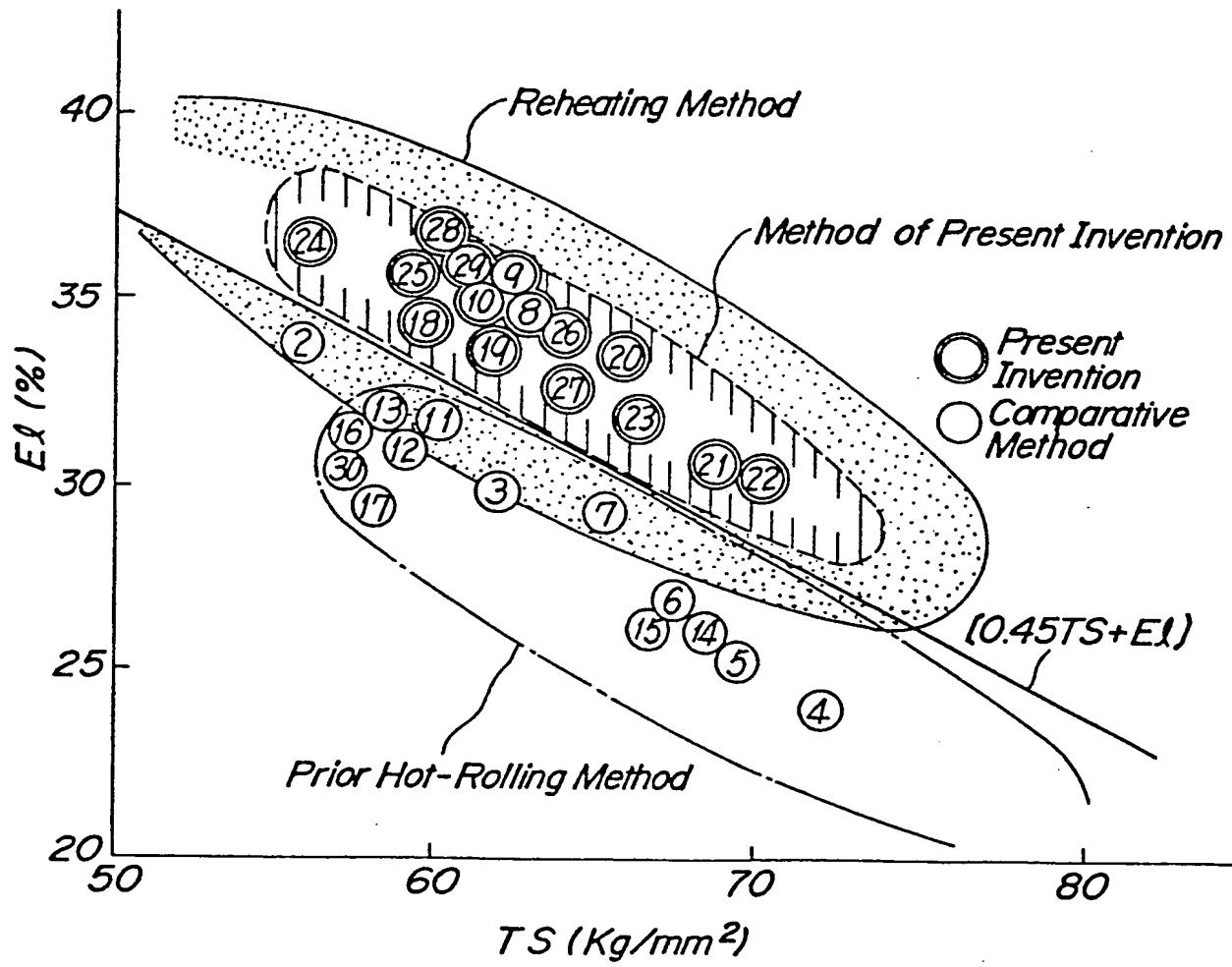
Temperature →

Time →

FIG_2

FIG.3

INTERNATIONAL SEARCH REPORT

International Application No   PCT/**0072867**

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ³

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.³   C21D 9/46, C21D 8/02, C22C 38/54

II. FIELDS SEARCHED

Minimum Documentation Searched ⁴

Classification System	Classification Symbols
I P C	C21D 9/46, C21D 8/02, C22C 38/54

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched ⁵

III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴

Category *	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
P	JP,A, 56-33429 (Sumitomo Metal Industries, Ltd.); 3. April. 1981 (3.4.81), Page 1, lower left column, line 4 to lower right column, line 17	1
P	JP,A, 56-105422 (Sumitomo Metal Industries, Ltd.) 21. August. 1981 (21.8.81), Page 2, upper left column, line 4 to upper right column, line 4	1

* Special categories of cited documents: ¹⁵

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"L" document cited for special reason other than those referred to in the other categories

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"T" later document published on or after the International filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search ²

April 16, 1982 (16.04.82)

Date of Mailing of this International Search Report ²

April 26, 1982 (26.04.82)

International Searching Authority ¹

Japanese Patent Office

Signature of Authorized Officer ²⁰

Form PCT/ISA/210 (second sheet) (October 1977)

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